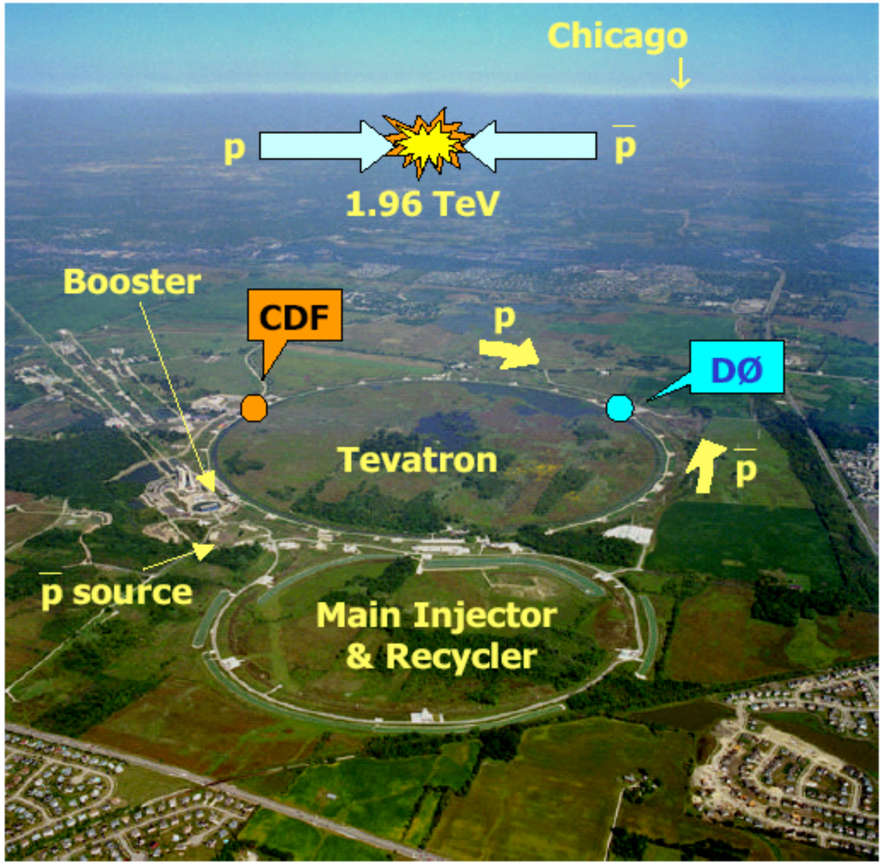
Top Mass Measurements



Petteri Mehtälä
University of Helsinki and
Helsinki Institute of Physics

On behalf of the
CDF and D0 collaboration

DIS 2008
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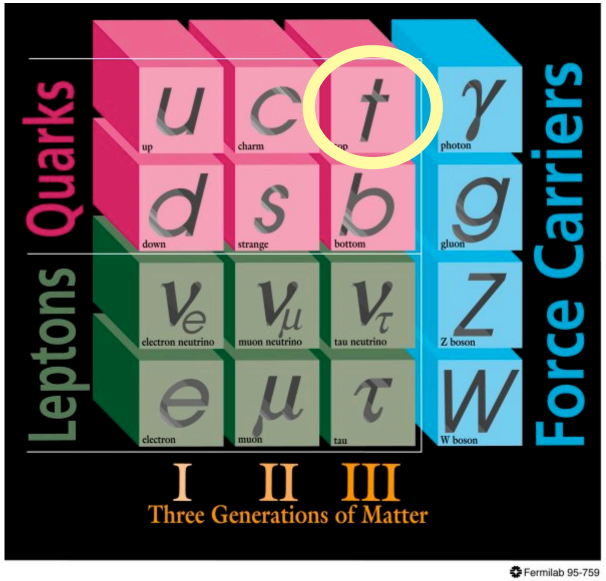
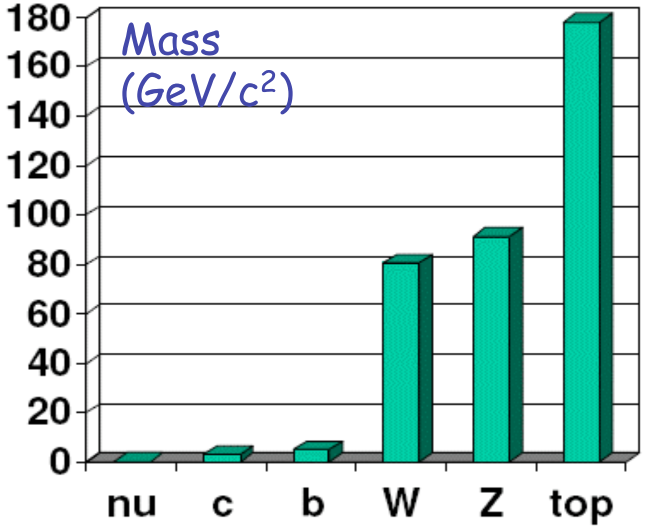
The Top quark

- Feels strong, electroweak and gravitational forces
- Life time τ=5x10^{-25} s, decays before hadronization
  - Allows mass measurement of a bare quark
- The heaviest known elementary particle
  - ~175 GeV/c^2
  - 40 x b-quark mass
- Currently studied only at Tevatron
- LHC will be a top factory
  - top is one of the benchmarks

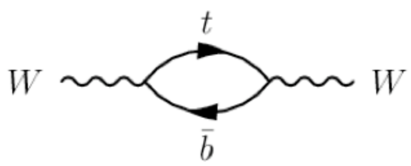


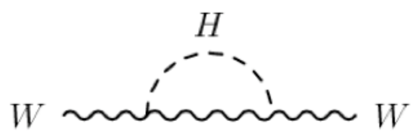


The Top Quark Mass

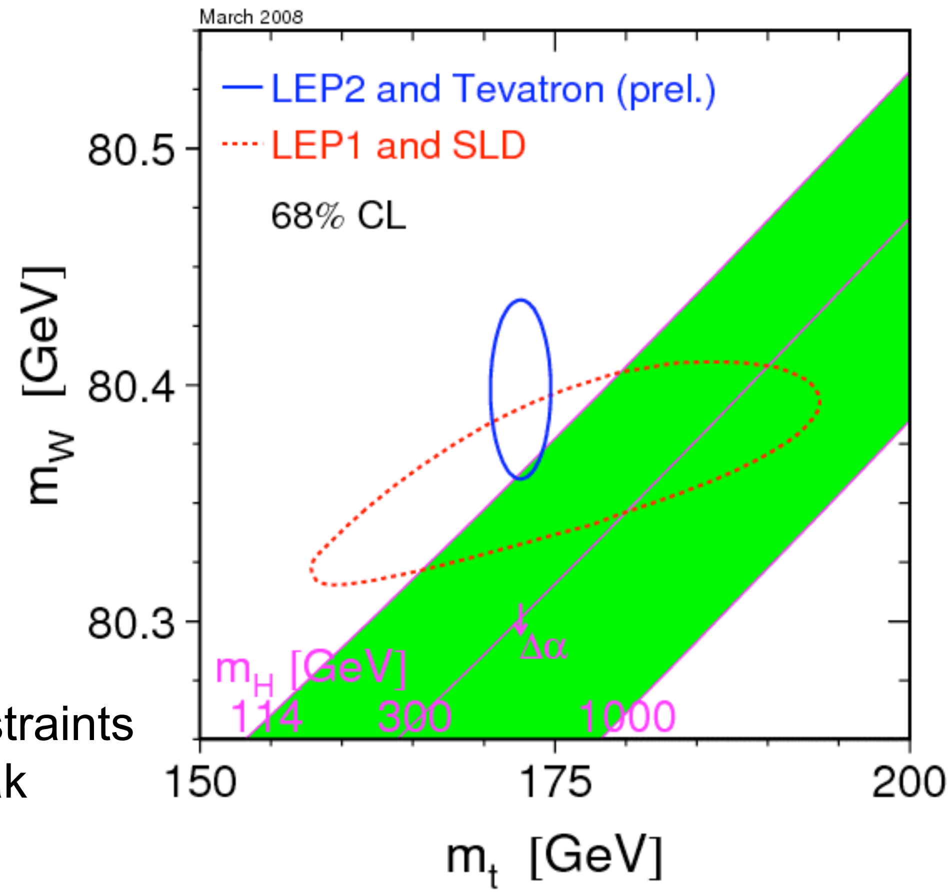
Top mass is a fundamental SM parameter

- important in radiative corrections





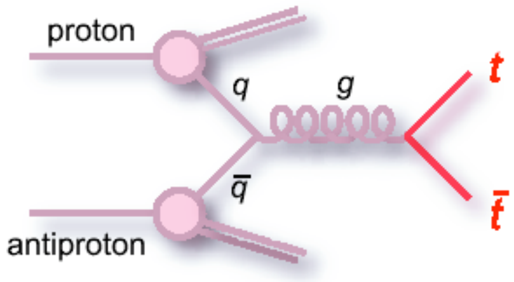
- Yukawa coupling ~1, special role in electroweak symmetry breaking??
- Consistency check of SM, and constraints M_{Higgs} with M_w and other electroweak precision measurements



Constraints on models beyond SM (SUSY)

The Top quark

At the Tevatron, mainly produced in pairs (σ = 7pb) via strong interaction.



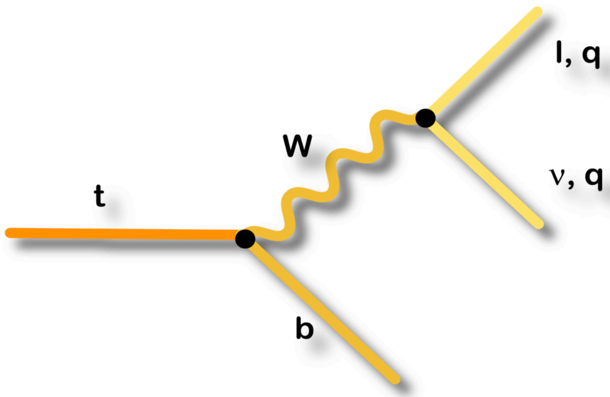
85%

15%

LHC (90%)

~100σ

Decays ~100% to Wb



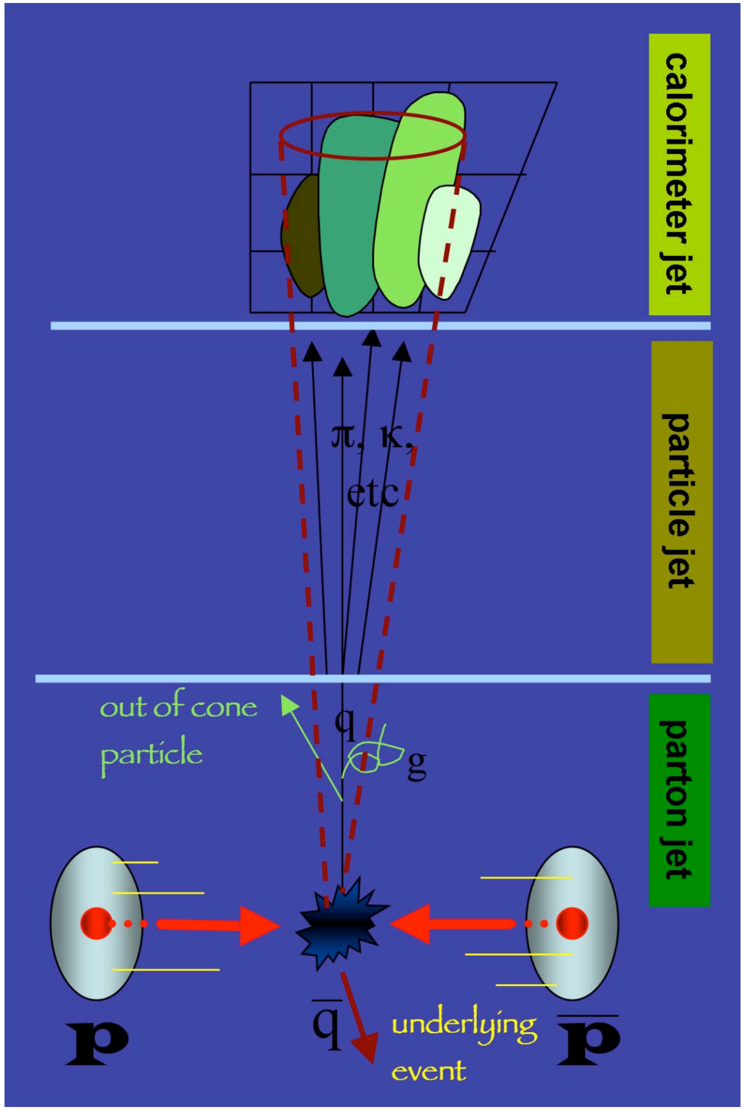
- Dilepton (BR~5%, small bkgds)

  2 leptons (e/μ), 2 b jets, missing E_T (2νs)
- Lepton+Jet (BR~30%, manageable bkgds)

  1 lepton(e/μ), 4 jets (2 b jets), missing E_T (1ν)
- All-hadronic (BR~44%, large bkgds)

  6 jets (2 b jets)

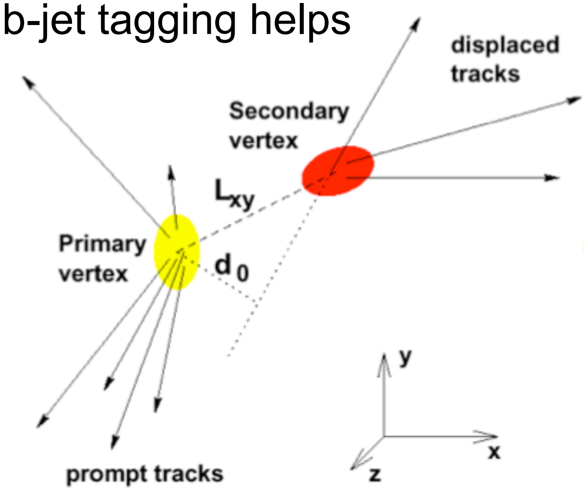
The jets in top mass analyses



- The jet energy scale (JES)
  - external measurement
  - In top decays: insitu calibration by W→ qq

    Scale jet energies: invariant mass of jj system need to match W mass

    $E_{jet} = E_{meas} + JES * \sigma_{JES}$ or $E_{jet} = E_{meas} * JES$
- The combinatorics
  - how to associate jets to the partons from top decays? b-jet tagging helps



- Radiation (ISR/FSR)
  - not all jets originate from the top decay

Analysis methods

- Template method
  - mass estimator, typically the top mass from kinematic fit
  - templates: probability density function from simulated top events for different generated top masses
  - fit templates to data distribution

- Event-by-event likelihood
  - Extract as much as possible information from the events
  - **Matrix element method** use theoretical prediction for top production and decay
  - Integrate over parton energies (and angles), assign probability to measure a jet given parton energy

Given event *x*, probability for M_t and JES

detector response for given parton

$$P(\vec{x}\,|\,M_t, JES) = N \int d\Phi \left|M_{t\bar{t}}(p;M_t)\right|^2 \prod_{objects} W(p,j)\, f_{PDF}F(q_1)\, f_{PDF}(q_2)$$

Parton-level phase-space

ME for top production and decay

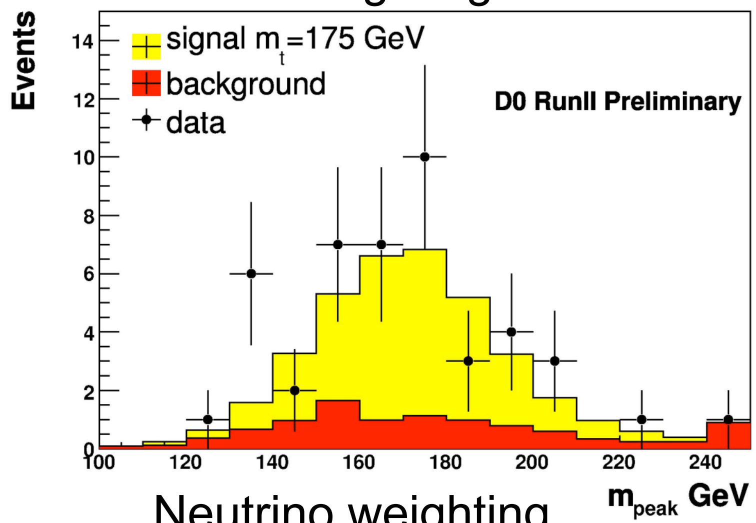
PDF for incoming partons

Dileptons channel

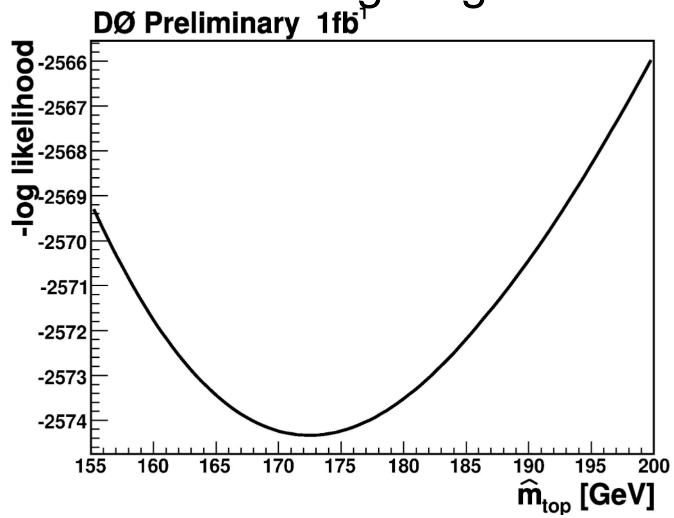
L = 1.05 fb^{-1}

- **Matrix weighting**
  - Integrate over possible parton solutions
  - Weight solutions by the consistency with PDF and measured lepton energies
  - Template for the top mass with largest weight
- **Neutrino weighting**
  - For each top mass, loop over pseudo-rapidities of the two neutrinos
  - Weight using consistency with missing P_T
  - Templates for mean and RMS of weight distributions

Matrix weighting



Neutrino weighting



- **Combined result**

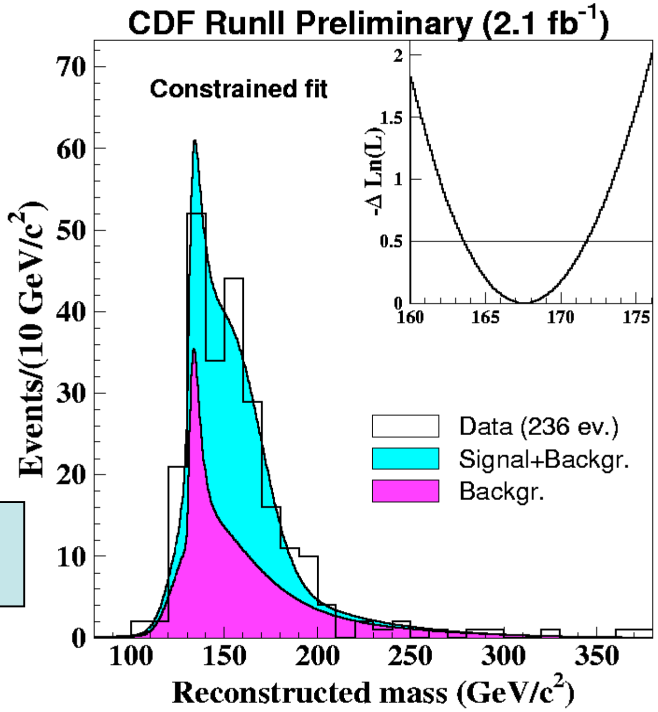
$$M_t = 173.7 \pm 5.4\ (\text{stat}) \pm 3.4\ (\text{syst})\ \text{GeV}/c^2$$

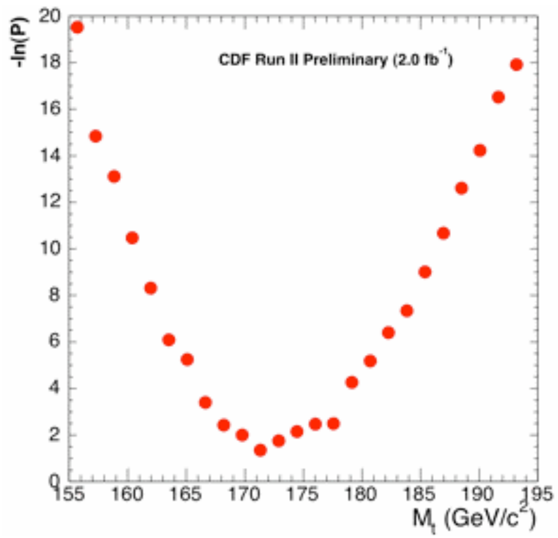
Dileptons channel

$L = 2.0\text{-}2.1\ fb^{-1}$

- **Neutrino weighting**
  - Loop over azimuthal angles of two neutrinos
  - templates for the weighted average top mass

$M_t = 167.7^{+4.2}_{-4.0}$ (stat.) ± 3.1 (syst.) GeV/c^2





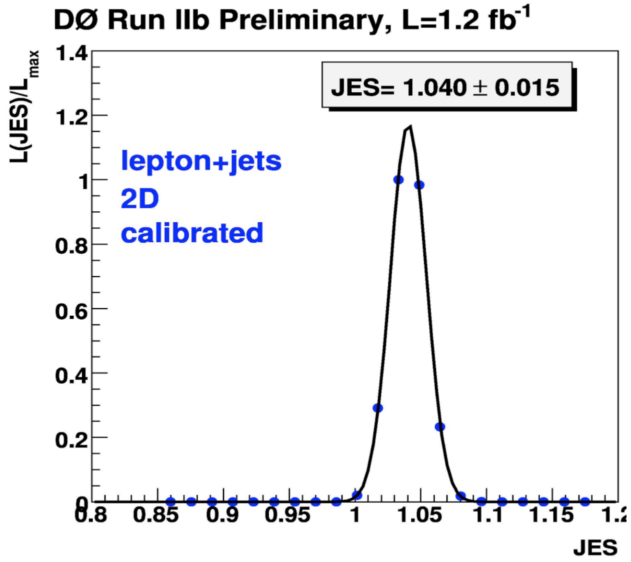
- **Matrix element**
  - Uses evolutionary neural network selection.
    Optimizes the resolution: 20% improvement in resolution.

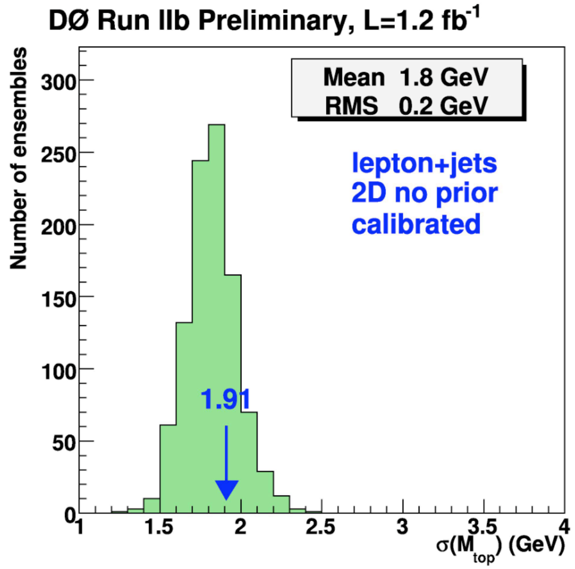
$M_t = 171.2 \pm 2.7$ (stat.) ± 2.9 (syst.) GeV/c^2

Lepton+jets channel

L = 2.1 fb^{-1}

- Matrix Element method
- Insitu JES measurement
- Neural net b tagging
- Currently most precise single top mass measurement in world!



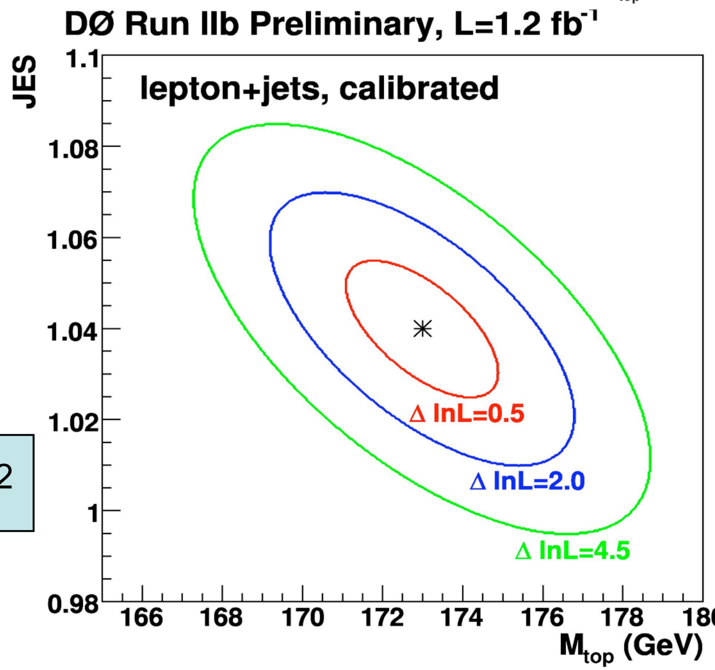


L = 0.9 fb^{-1}:

M_t = 170.5±2.5 (stat+JES)±1.4 (syst) GeV/c^2

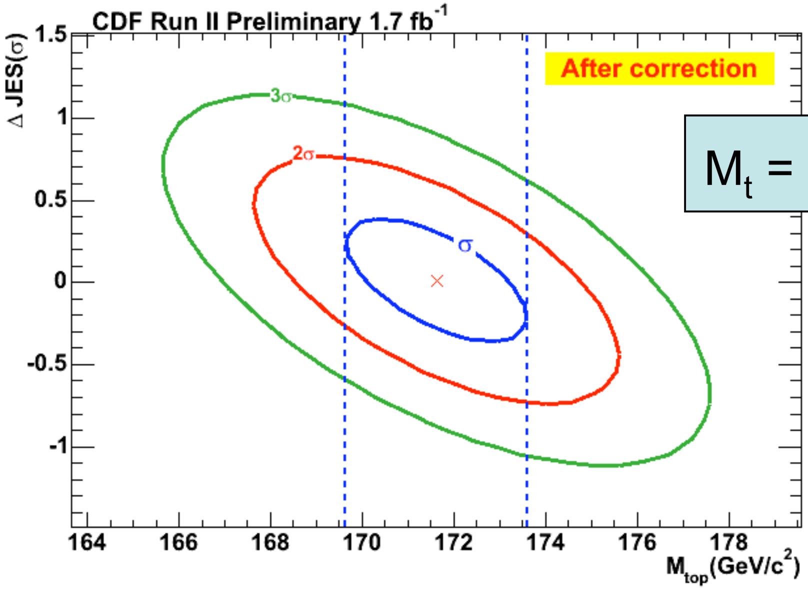
L = 1.2 fb^{-1}:

M_t = 173.0±1.9 (stat+JES)±1.0 (syst) GeV/c^2



M_t = 172.2 ± 1.1 (stat) ± 1.6 (syst+JES) GeV/c^2

Lepton+jets channel

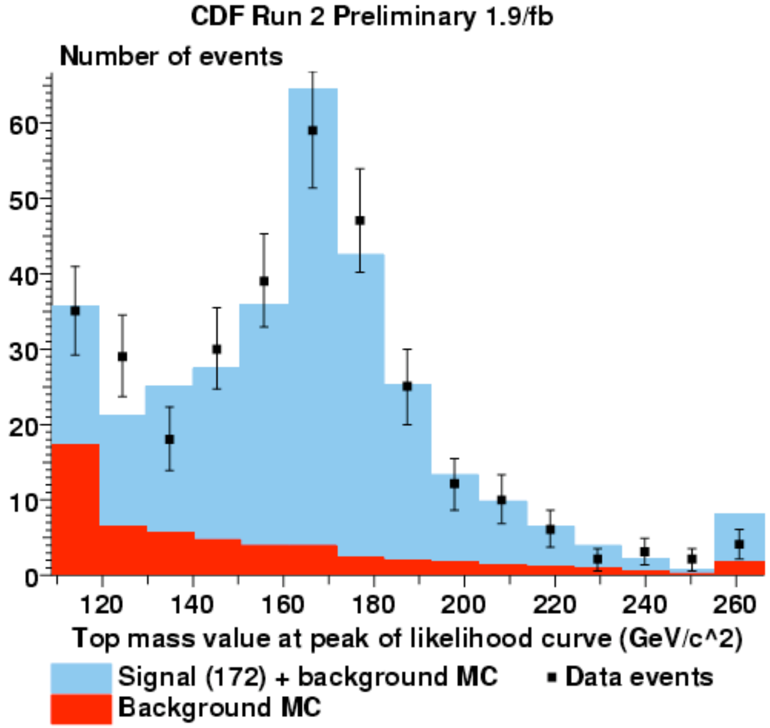


- Matrix Element method L = 1.7 fb^{-1}

M_t = 171.6 ± 2.0 (stat+JES) ± 1.3 (syst) GeV/c^2

L = 1.9 fb^{-1}

- Weight permutations using tagging probability
- Event-by-event NN discriminant for background
- The expected background is subracted from the likelihood

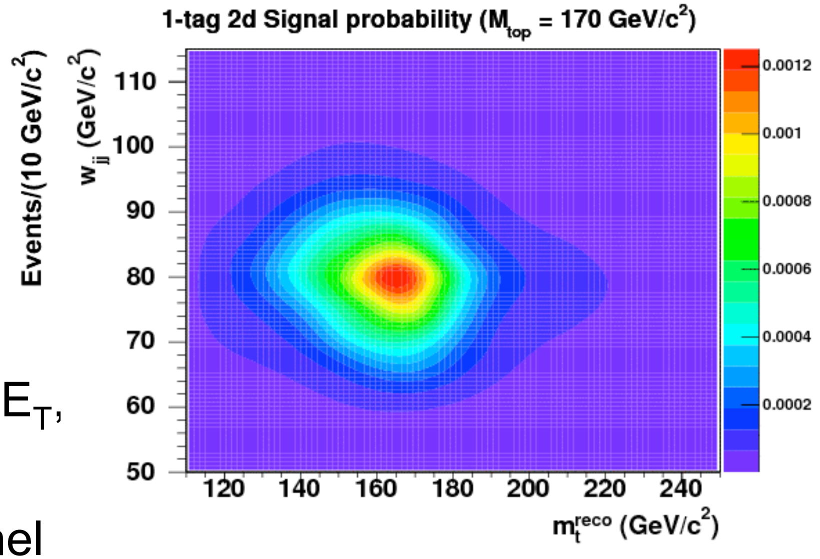


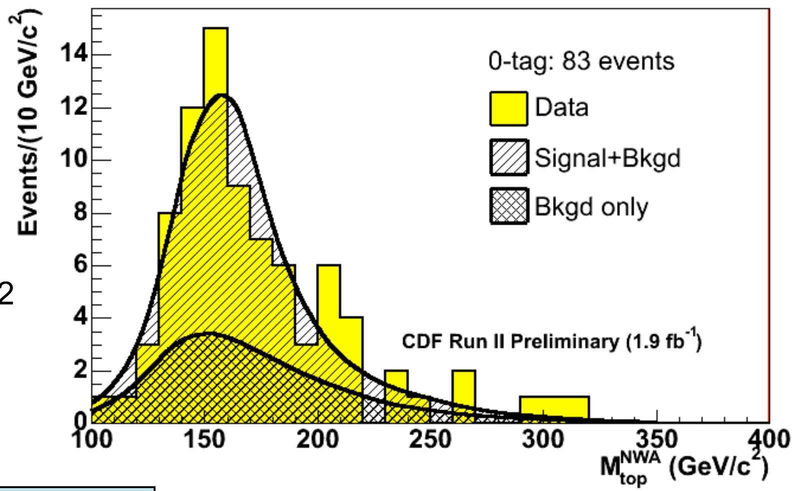
M_t = 172.7 ± 1.8 (stat.+JES) ± 1.2 (syst) GeV/c^2

Lepton+jets and dilepton combined

$L = 1.9\ fb^{-1}$

- Template method with 2D fits
  - Lepton + jets: top mass and dijet mass
  - Dileptons: neutrino weighting
    top mass and H_T (scalar sum of missing E_T, lepton P_T, jet P_T)
- Combine both lepton+jets and dilepton channel
- No assumptions about correlated systematics
- Dileptons benefit from the use of insitu JES calibration of lepton+jets events





Lepton + jets:

M_t = 171.8±1.9 (stat+JES)±1.0(syst) GeV/c^2

Dilepton:

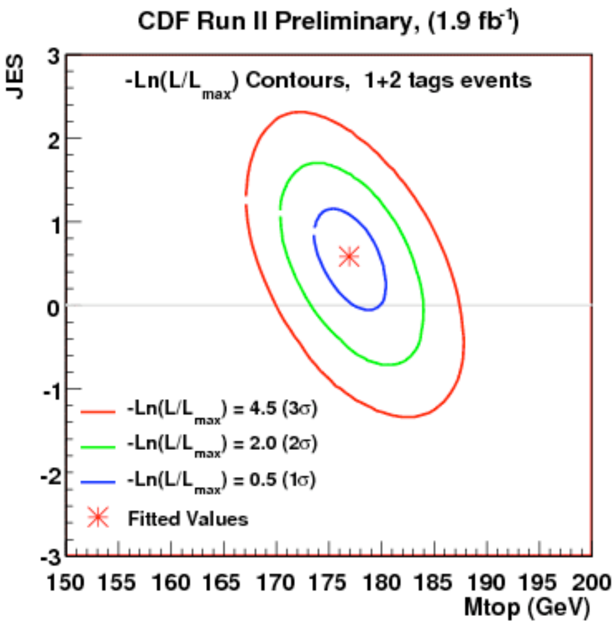
$M_t = 171.6^{+3.4}_{-3.2}$ (stat) ± 3.8(syst) GeV/c^2

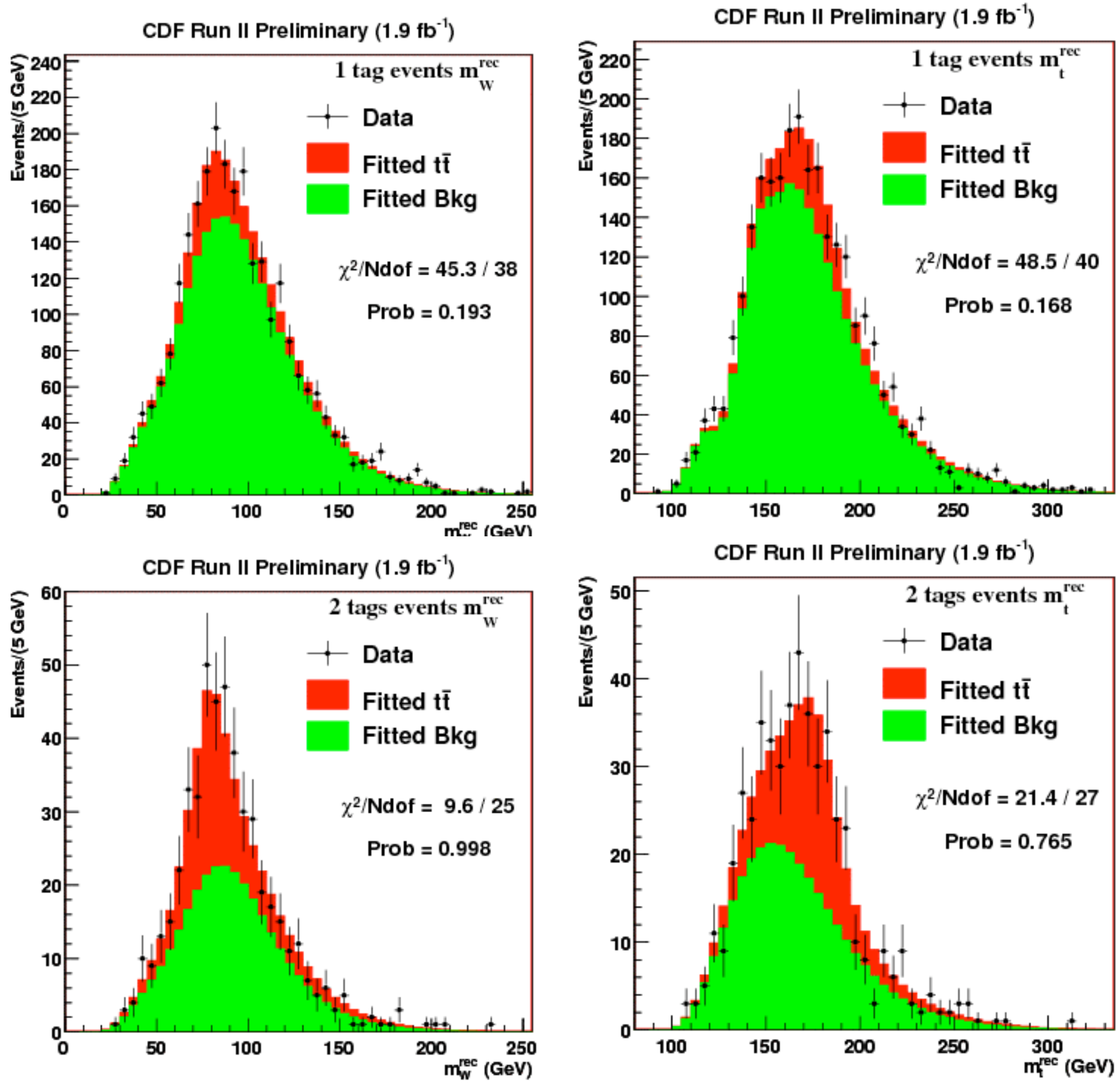
M_t = 171.9 ± 1.7 (stat+JES) ± 1.0 (syst) GeV/c^2

All-hadronic channel

$L = 1.9\ fb^{-1}$

- Template method
- 2D fit: top mass and JES
- NN-selection to reduce background
- Data driven background model





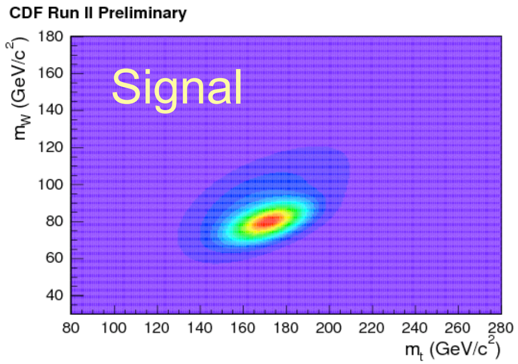
$M_t = 177.0 \pm 3.7\ (\text{stat+JES}) \pm 1.6\ (\text{syst})\ \text{GeV}/c^2$

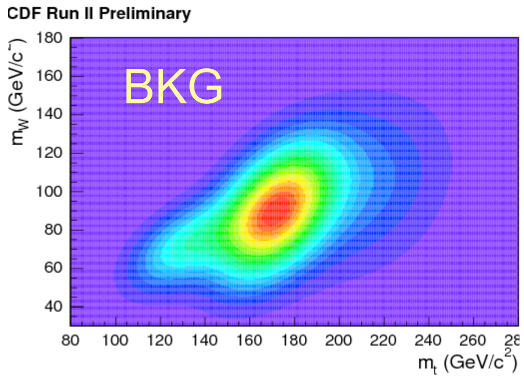
All-hadronic channel

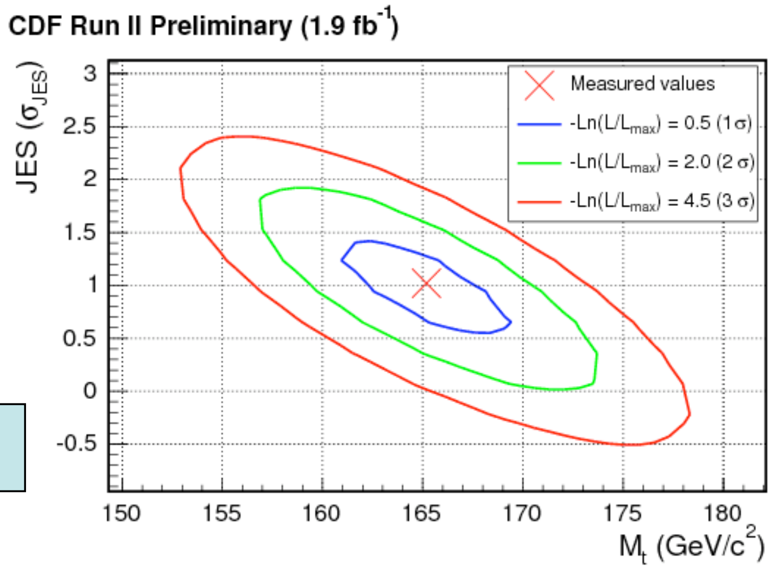
L = 1.9 fb^{-1}

- Use combined matrix element and template method:
  - For signal simplified matrix element
  - For background and poor signal events use template
- NN-selection and at least 2 b tags
  - Clean sample S/B ~ 2/3
- Signal fraction is measured from data

Source	ΔM_t (GeV/c^2)
ISR/FSR	1.2
MC Generator	0.8
Residual JES	0.7
Inst. lumi.	0.7
Bg Fraction	0.5
Bg Shape	0.4
PDF	0.4
B-JES	0.3
Calibration	0.2
Bg Statistics	0.07
Total	1.9







M_t = 165.2 ± 4.4 (stat+JES) ± 1.9 (syst) GeV/c^2

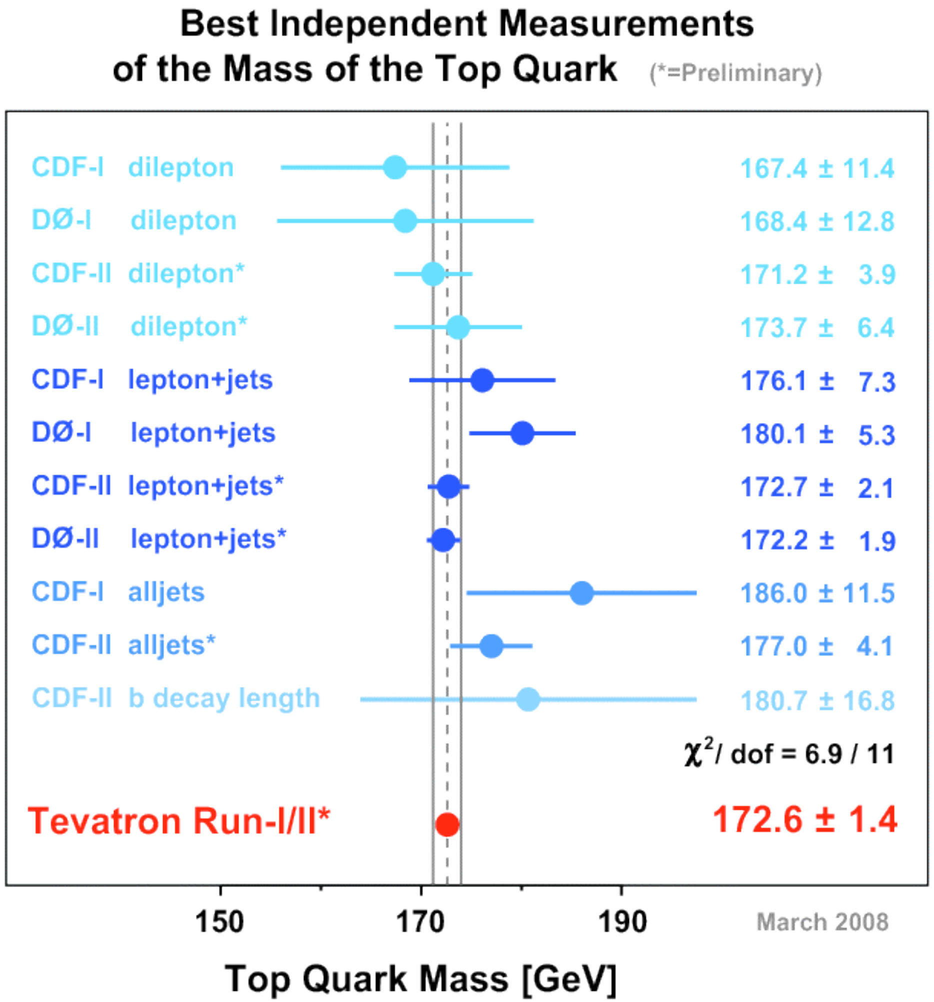
Combinations

- Jet Energy Scale still most dominant systematic
- Many analyses still gain from increased luminosity

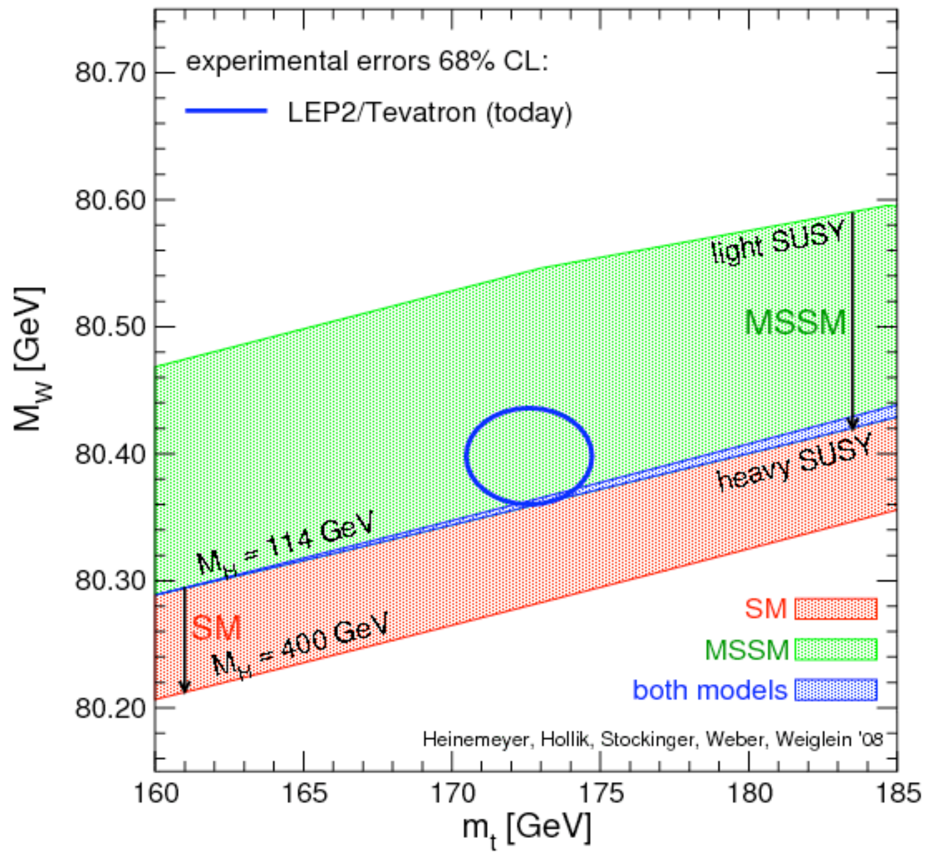
Run II Measurement	CDF di-l	D0 di-l	CDF l+j	D0 l+j	CDF all-j	CDF lxy	world average
$\int Ldt$ (fb^{-1})	2.0	1.1	1.9	2.1	1.9	0.7	
Result	171.2	173.7	172.7	172.2	177.0	180.7	172.6
Jet Energy Scale	2.5	3.1	1.5	1.3	2.0	0.3	0.9
Signal	0.7	0.8	0.6	0.7	0.6	1.4	0.5
Background	0.4	0.6	0.6	0.4	1.0	7.2	0.4
Fit	0.6	0.9	0.2	0.1	0.6	4.2	0.1
MC	0.7	0.2	0.4	0.0	0.3	0.7	0.2
Systematic	2.8	3.4	1.7	1.6	2.4	8.5	1.1
Statistical	2.7	5.4	1.2	1.1	3.3	14.5	0.8
Total Uncertainty	3.9	6.4	2.1	1.9	4.1	16.8	1.4

- Statistical uncertainties: uncorrelated
- Most of the systematics: correlation between other analyses

Tevatron Combination



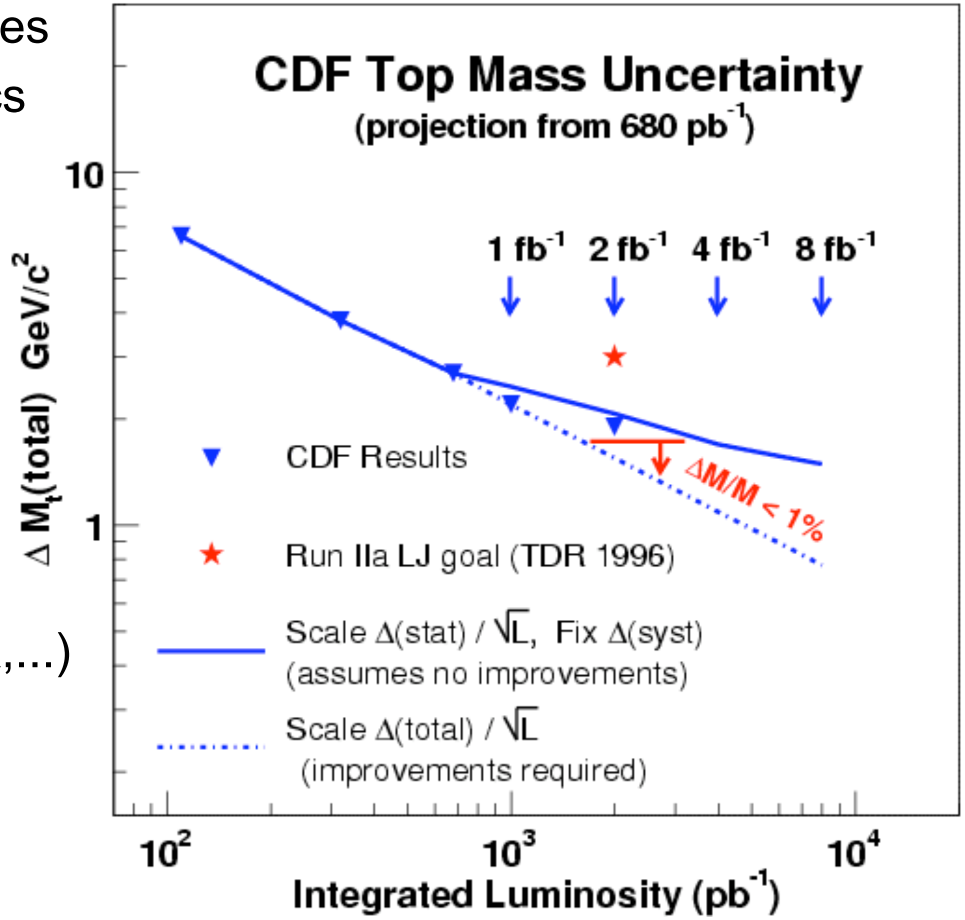
http://tevewwg.fnal.gov/top



- **Precision of δM/M = 0.8% !**
- **SM Higgs < 160 GeV/c² with 95% CL (< 190 GeV/c² including LEP-2 limit)**

Future prospects

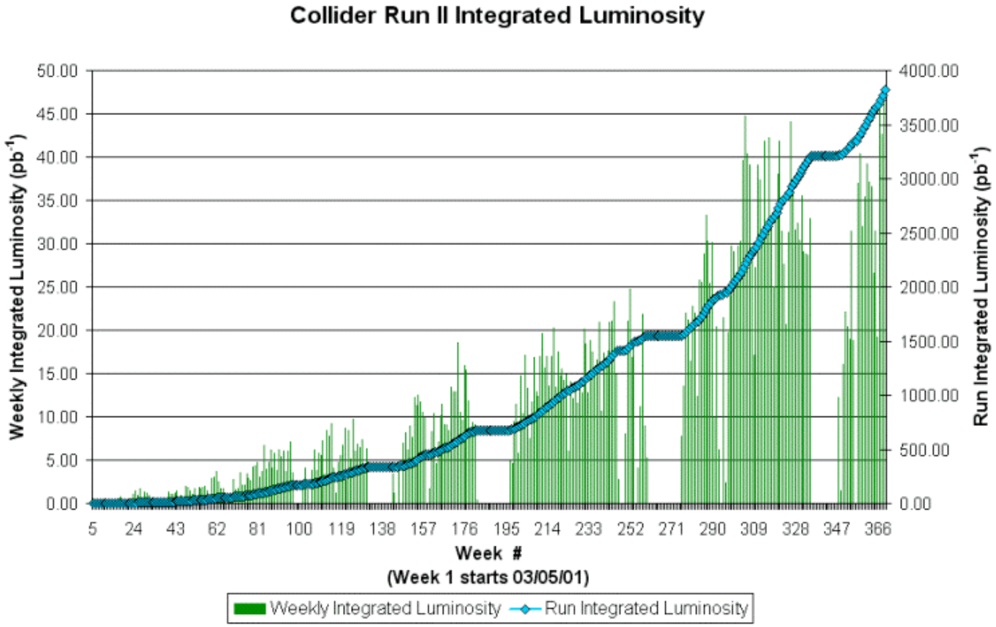
- CDF as an example
- With 2 fb^{-1} top mass uncertainty beats the uncertainty projected from 680 pb^{-1} by only accounting increased luminosity
  - Improvements in analysis techniques
  - Better understanding of systematics



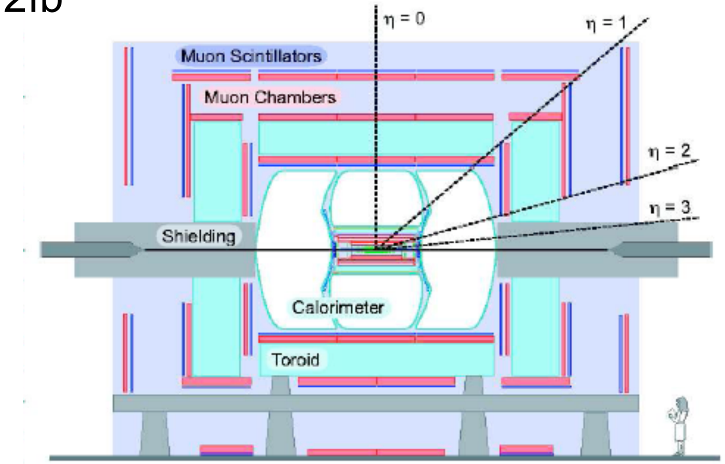
- With full data set of 8 fb^{-1}
  - Systematics dominate
    - ⇒Need to push down!
    - ⇒Other sources of systematics come more dominant when JES systematics decreases with more statistics (ISR/FSR,...)
  - Precision of 1 GeV is close!

BACKUP

Tevatron experiments



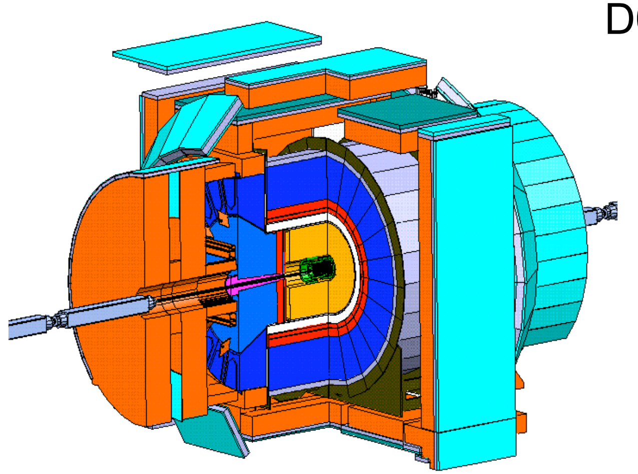
- Delivered almost 4 fb^{-1}
- More than 3 fb^{-1} on tape (both experiments)
- Current top mass analyses use up to ~2fb^{-1}



D0 detector

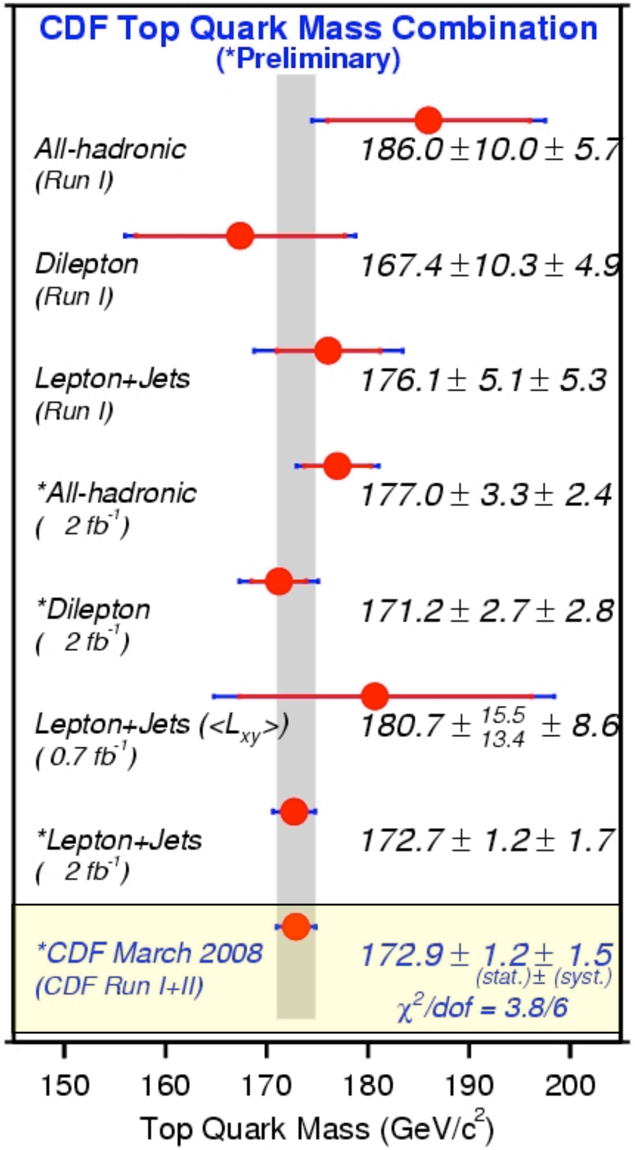
- Calorimeters ($\sigma/E \sim 80\% / \sqrt{E}$)
- Precision tracking with SI
- Muon chambers
- Excellent muon coverage(D0), excellent tracking (CDF)

Multi-purpose detector;
precision measurements
search for new physics

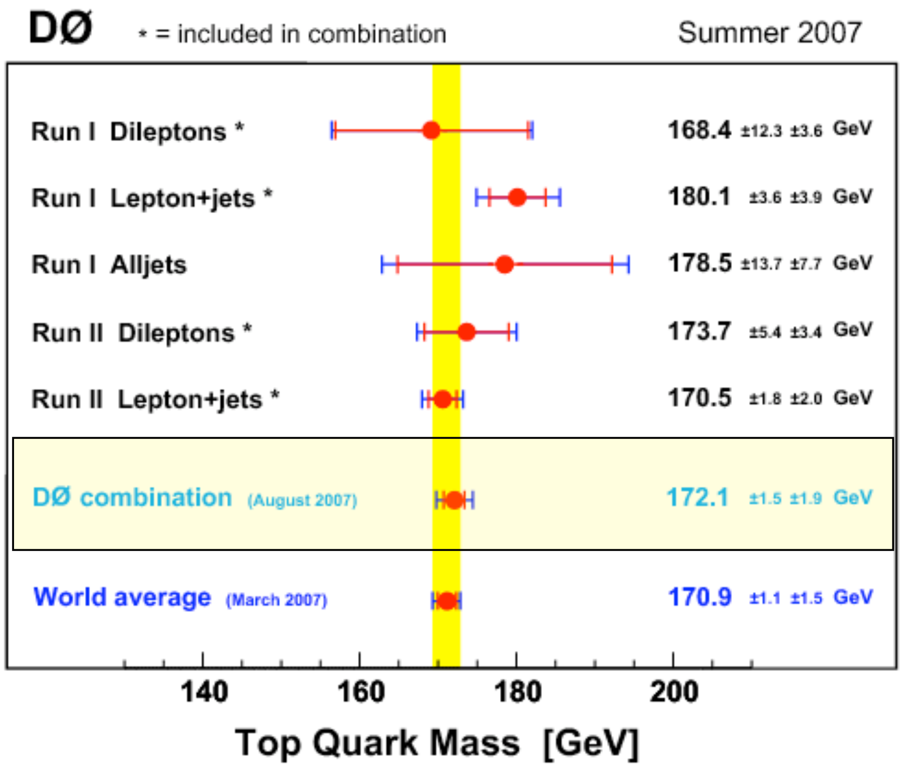


CDF detector

Combinations



- Many other top mass measurement performed in CDF and D0



All-hadronic analyses

- Both analyses use the same neural net selection
  - Template method uses events with 6-8 jets and one or two b-tag
  - Ideogram analysis uses events with exactly 6 jets and at least two b-tags
  - Overlap between samples small, but most of the mass information comes from the sample used by Ideogram analysis
- The correlation between analyses (by using number of overlapping events and the contribution of these events in template analysis) is something between 0.42 and 0.67 (absolute maximum).
- Compatibility using the t-test and JES fixed to zero
  - Template method measures 179.0 ± 3.0 GeV (stat.)
  - Ideogram analysis measures 172.1 ± 2.7 GeV (stat.)
  - The t-test gives using only statistical uncertainties:

    67% correlation: 2.96 (standard deviations)

    45% correlation: 2.2

    25% correlation: 1.97
- More studies on going to get better understanding of the compatibility